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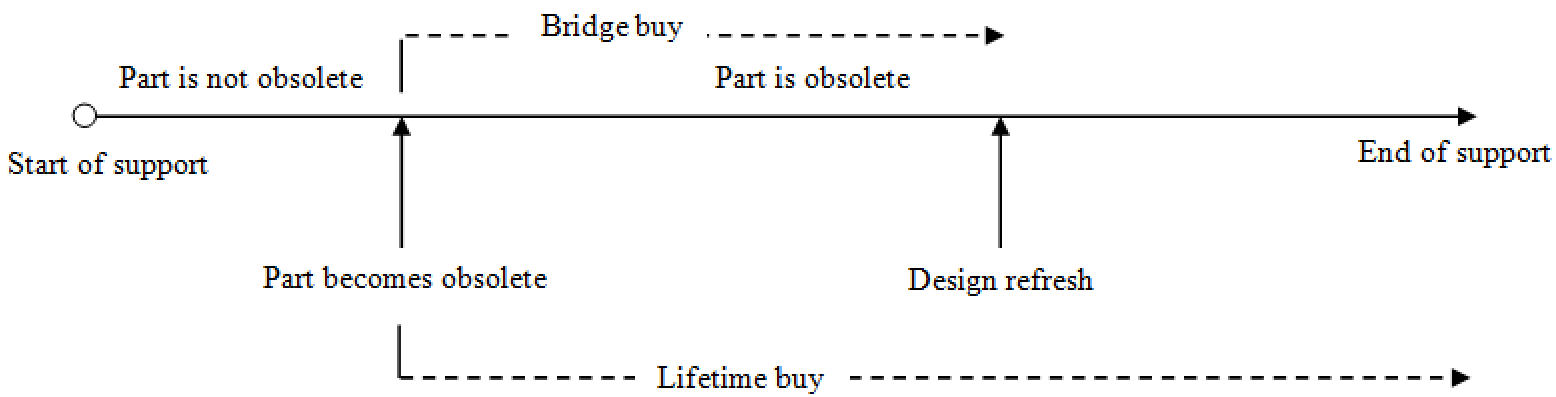
Lifetime Buy
(Life of Type - LOT Buy, All Time Buy)

- When a part becomes obsolete, lifetime buy is a mitigation approach that involves the purchase and storage of a part in a sufficient quantity to meet current and (expected) future demands.



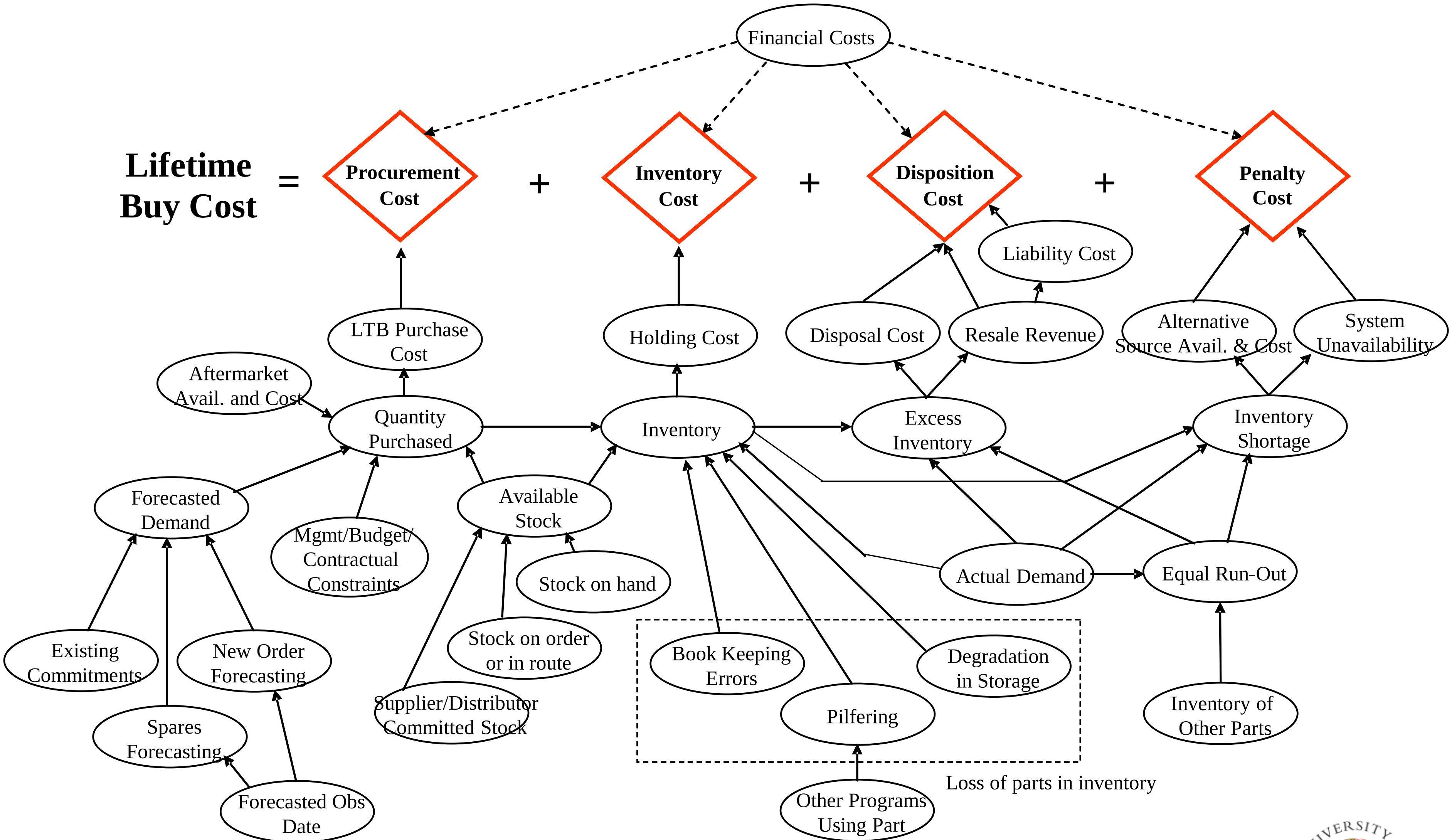
- The opportunity to make lifetime buys is usually offered by manufacturers prior to part discontinuance. Lifetime buys play a role in nearly every part obsolescence management portfolio.
- Advantages of Lifetime Buys:
  - Design modifications and re-qualification is not required
  - Original warranty on parts from the manufacturer is available
  - Management often views lifetime buys as a straightforward option

An Example: Lifetime Buys

Lifetime Buy Cost = **Procurement Cost** + **Inventory Cost** + **Disposition Cost** + **Penalty Cost**

Buying Shoes

Lifetime Buy Cost



The Lifetime Buy Problem

How many parts should you buy?

Every organization has developed some institutional knowledge governing lifetime buy *buffer* sizes:

- *Buffer* = the number of parts in excess of the forecasted demand that are purchased
- For parts that cost less than "*x*" we buy 25% over demand
- For more expensive parts we buy 10% over demand
- Buffer sizes are, however, trumped by minimum buy sizes and what management (or the customer) is willing to signoff on

The lifetime buy problem consists of two steps:

1. Forecasting future part needs (demand forecasting)
2. Optimizing lifetime buy quantities (lifetime buy forecasting)

Our Focus

The Lifetime Buy Problem (continued)

Optimizing lifetime buy quantities (lifetime buy forecasting):

Starting with a demand forecast plus all the issues in the influence diagram (and uncertainties in everything), what is the best quantity of parts to buy?

- Stochastically distribute demand
- Asymmetric over- and under-buy penalties
- Non-negligible inventory costs
- Cost of money (non-zero WACC)
- Uncertain end of support date
- “Must support” requirement

<u>Bottom Line:</u>
Asymmetric penalties, cost of money and non-zero holding costs mean that the optimum buy isn’t the forecasted demand

“Robust” optimum required = an optimum that accounts for uncertainties

Relevant Literature on Lifetime Buy Optimization

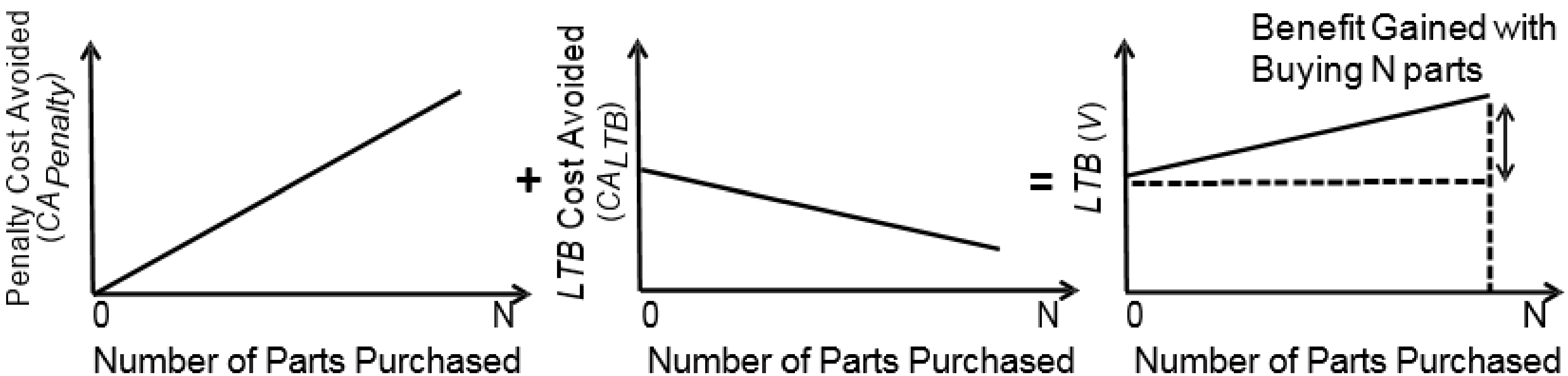
- “Final Order” problem in operational research
  - Teunter et al. (1998, 1999) – spare parts for manufacturing equipment
  - Feng et al. (2007); Bradley and Guerrero (2009) – matched sets
  - Elegant, but either not applicable to electronic parts or vastly over-simplified
- Newsvendor problem
  - Asymmetric penalty models, but …
  - Generally ignore time (don’t model holding costs or cost of money)
  - Sandborn (2013) – cost of money included, but no holding costs
- Stochastic buy quantity models
  - Many simple spreadsheets for forecasting quantities, <u>not</u> cost models
  - Leifker et al. (2014) – dynamic programming, contract extension sensitivity
- Real options models
  - Burnetas and Ritchken (2000) - option to delay the buy
- Concurrent refresh planning and lifetime buy quantity models
  - Porter (1998) – equal order quantity (EOQ) model
  - Sandborn (2013) – extension of Porter (1998) model
  - Cattani and Souza (2003) – single refresh with lifetime buy optimization
  - Singh and Sandborn (2006) – discrete-event simulation refresh planning
  - Josias (2009) – real options refresh optimization

Real Options

- A real option is the right, but not the obligation, to undertake certain business initiatives, such as deferring, abandoning, expanding, staging, or contracting.
- Real options differ from financial options in that they apply to tangible assets that are not typically traded as securities.
- Unlike conventional net present value analysis (discounted cash flow analysis) and decision tree analysis, real options analysis models the flexibility to alter the course of action in a real asset decision, depending on future developments.
- The analysis of options focuses on valuation under uncertainty:
  - If there was no uncertainty, the value of an option would be trivial to determine.
  - However, everything is uncertain and the future returns are generally highly asymmetric (upside ≠ downside).
  - For financial options, the question is what should I pay to buy the option?
  - For real options the questions are what is the value I get from the option and when do I exercise the option?

Real Options Analysis - Approach

- Real options analysis requires that one define “value” over time
- We will start by defining value as a function of number of parts purchased
- All the costs are positive (i.e., *avoided* costs) in this formulation.

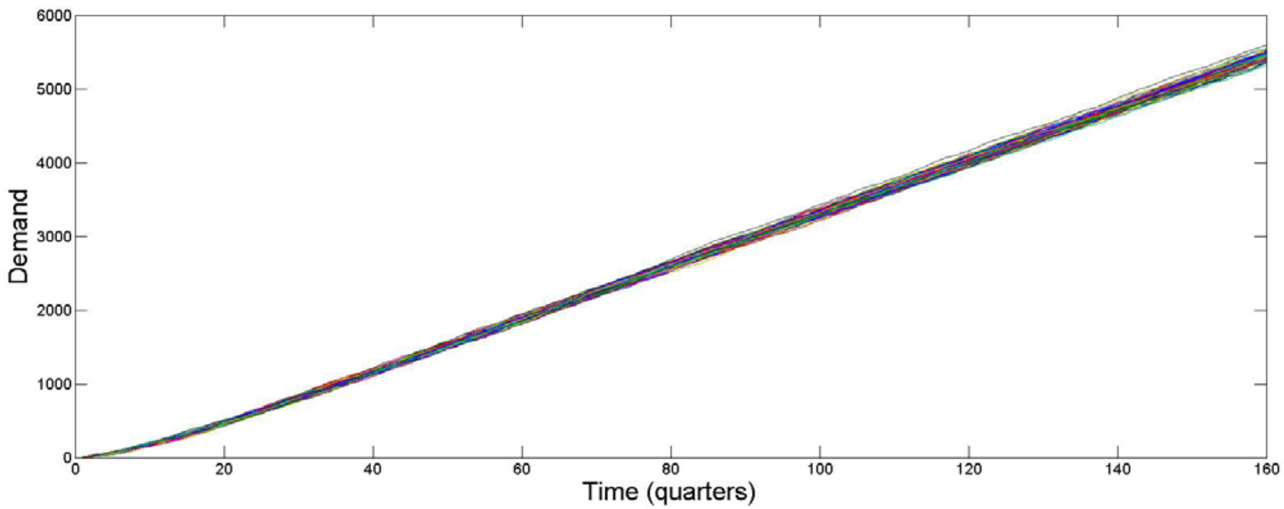


$$V = CA_{Penalty} + CA_{LTB}$$

- Objective = Find the number of parts to purchase that maximizes value (V)
- To solve this as a real options problem we must cast the formulation in terms of time (not parts purchased) ….

Buy-To Time

- Uncertainties in future demand create many different possible "demand paths"
- Demand paths are created by sampling time-to-failure distributions from the obsolescence date (last order date) to the end of support (*EOS*)

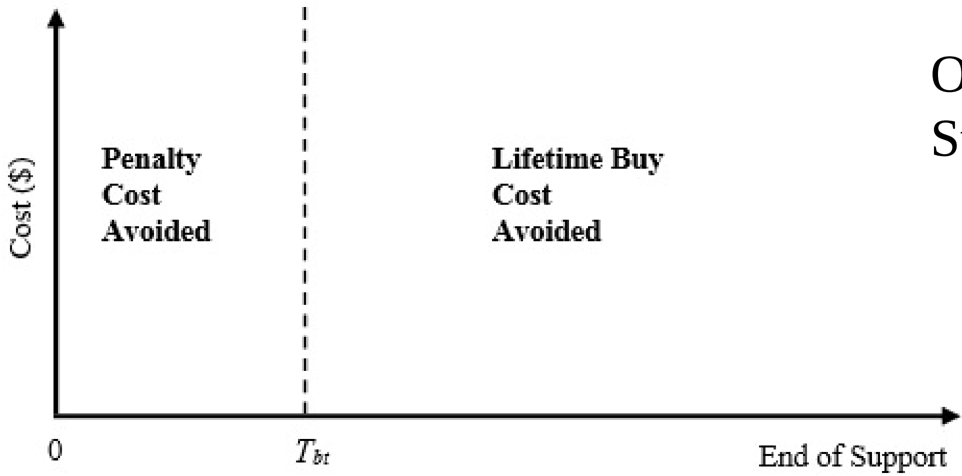


100 possible demand paths for a lifetime buy part (no EOS uncertainty)

- Buy-to time (T_{bt}) = the length of time (in a demand path) to buy parts for
- Objective = determine the optimum single buy-to time for all the possible demand paths

Option = Option to buy only enough parts to support the system to a point in time that is earlier than the end of support (*EOS*) date for the system – stopping the buy early option

Valuation of the Option



Option:
Stopping the buy prior to the EOS

For the i^th simulated demand path:

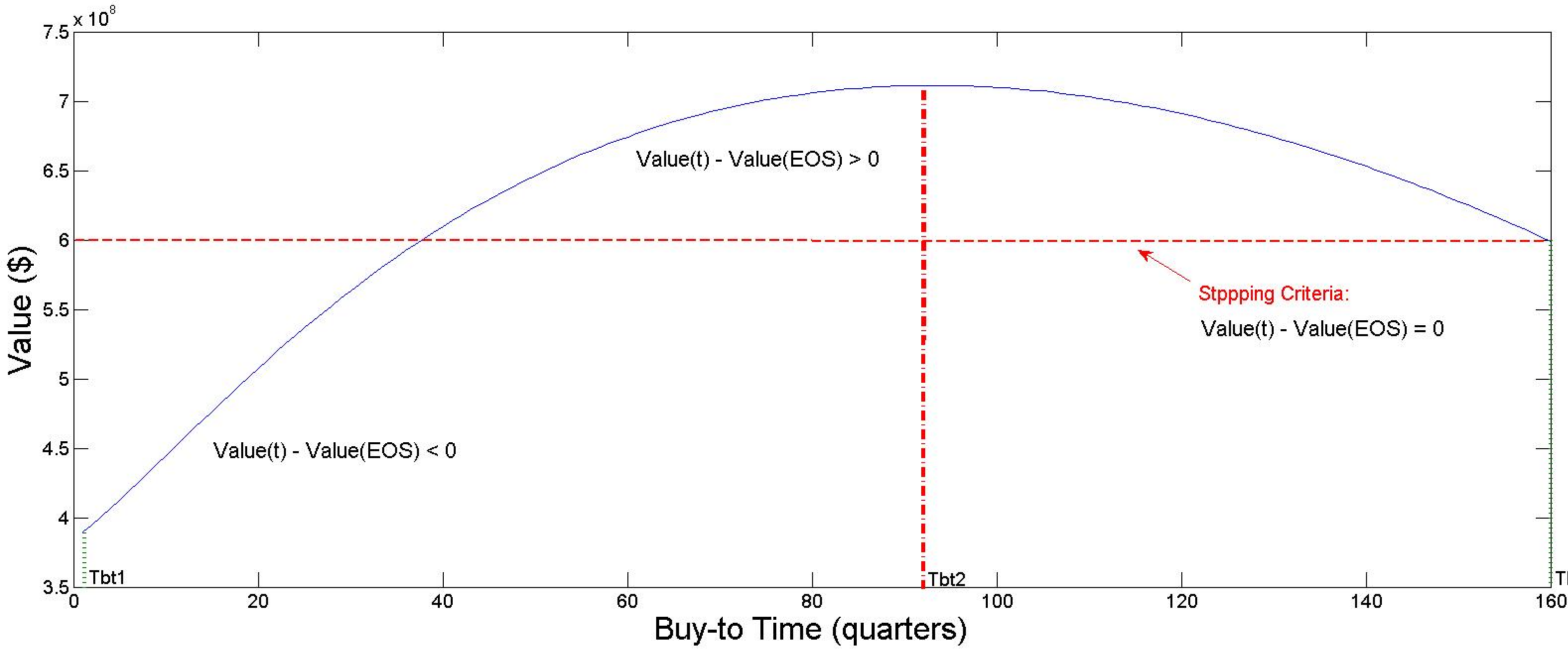
$$V_i(T_{bt}) = \overbrace{\left[\sum_{t=0}^{EOS}(L_i(t)+P_i(t)) - \sum_{t=T_{bt}}^{EOS}(L_i(t)+P_i(t))\right]}^{\text{Under-buy penalty avoided}} + \overbrace{\left[LTB_i(EOS) - LTB_i(T_{bt})\right]}^{\text{LTB cost avoided}}$$

$$LTB_i(T_{bt}) = IB_i(T_{bt}) + HC_i(T_{bt})$$ Lifetime buy cost

L and *P* = lump (at buy run out) and per part penalties, respectively, imposed after the *LTB* runs out
IB = the initial buy cost
HC = the sum of all the holding costs for the lifetime buy of parts

Stopping Criteria

- We treat the problem as a series of European options (where each option has a specified buy-to time)
- For a particular buy-to time (T_{bt}), each demand path is assessed as:



$$Value(T_{bt}) - Value(EOS) \geq 0 \rightarrow \text{exercise the option} \rightarrow Value(T_{bt}) = Value(T_{bt})$$

$$Value(T_{bt}) - Value(EOS) < 0 \rightarrow \text{do not exercise the option} \rightarrow Value(T_{bt}) = Value(EOS)$$

The final value of exercising the option at a specific buy-to date is obtained by averaging the paths' values, $V_i(T_{bt})$:

$$V(T_{bt}) = avg(V_i(T_{bt}) | i = 1:N)$$

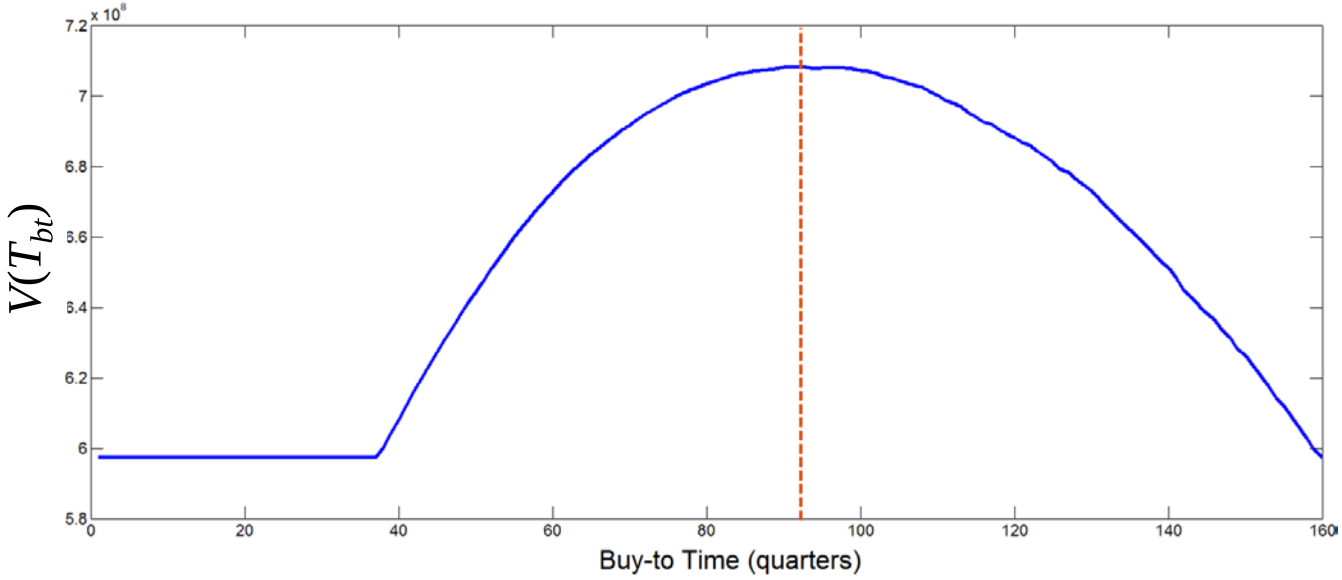
Demonstration Case

The following application-specific lifetime buy problem is assumed:

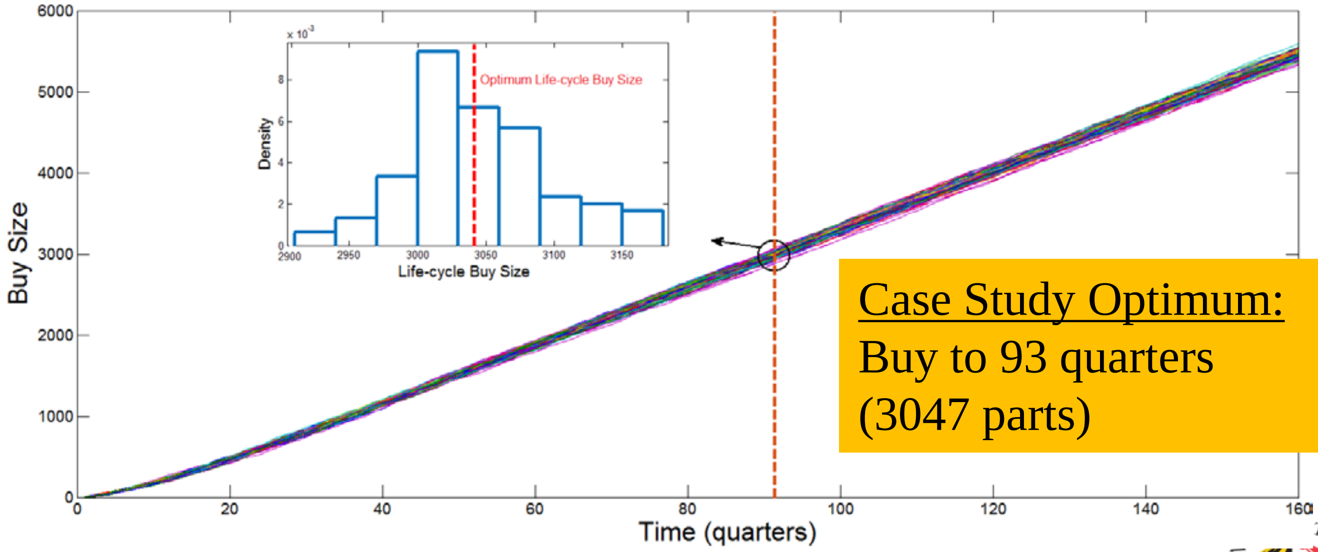
1. Part reliability (mean TTF of 7 years):
   a. The Weibull location parameter = 0
   b. The Weibull shape parameter = 1.5
   c. The Weibull scale parameter = 7.7541 years
2. Cost analysis:
   a. Number of systems to support = 1000
   b. End of support (*EOS*)= 40 years (160 quarters)
   c. Initial buy size = to be determined
   d. Part purchase price (at the lifetime buy) = $110/part
   e. Riskless interest rate = 3%/year
   f. Holding cost = $38.5/part/year
3. Penalties:
   a. Under buy lump penalty cost (one-time cost) (*L*) = $110,000
   b. Under buy per part penalty cost (*P)* = 0
   c. Over-buy penalty cost = $55/part

Demonstration Case (continued)

The value, $V(T_{bt})$ of exercising the "stopping the buy early" option for the demonstration case.



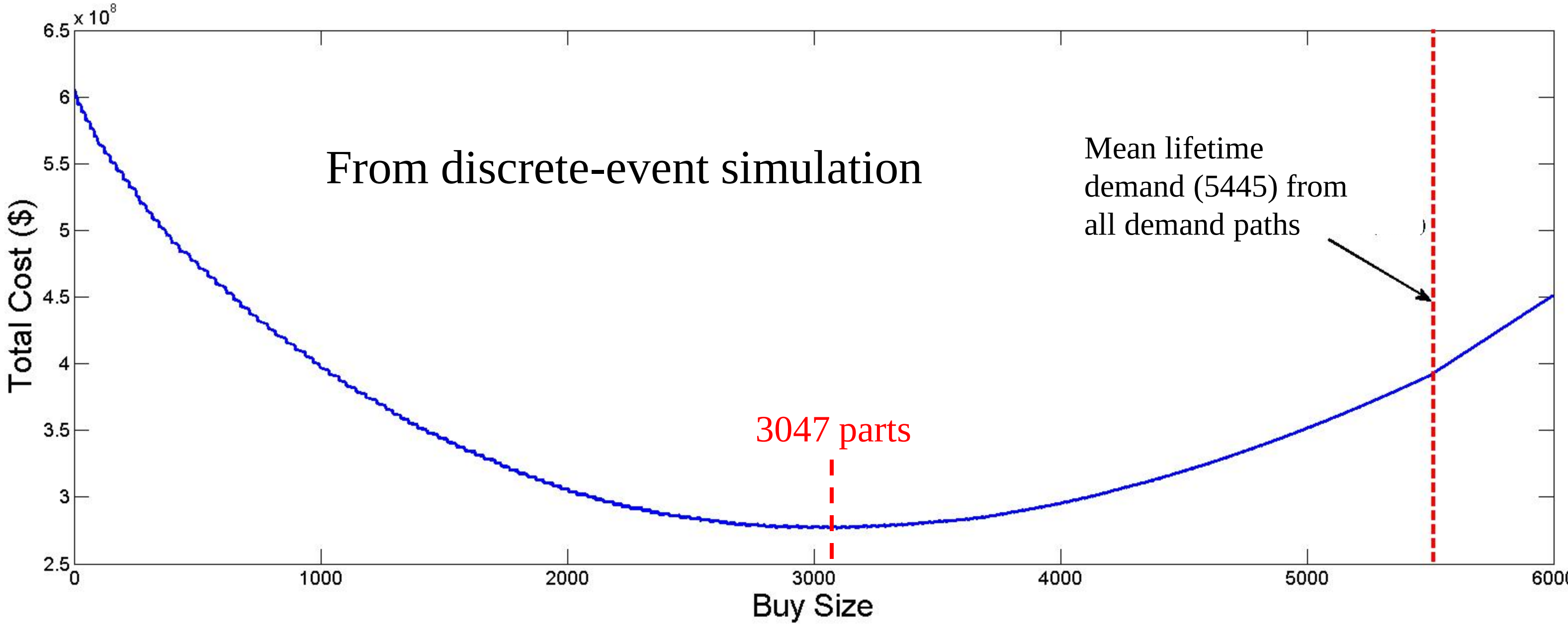
The optimum lifetime buy size obtained from exercising the "stopping the buy early" option for the example case.



<u>Case Study Optimum:</u>
Buy to 93 quarters
(3047 parts)

Solution Validation

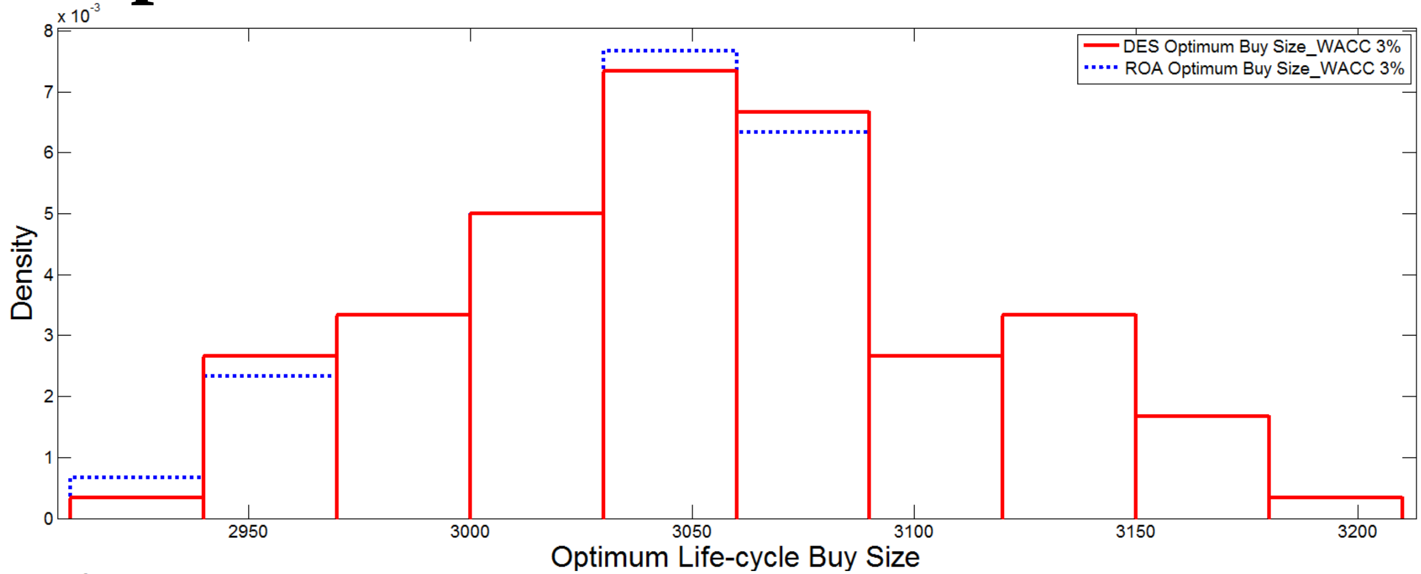
If we require all demand paths to use a single buy size value, i.e., each path has no inherent flexibility relative to the other paths, then we expect a stochastic discrete-event simulation (DES) to produce the same result as ROA.



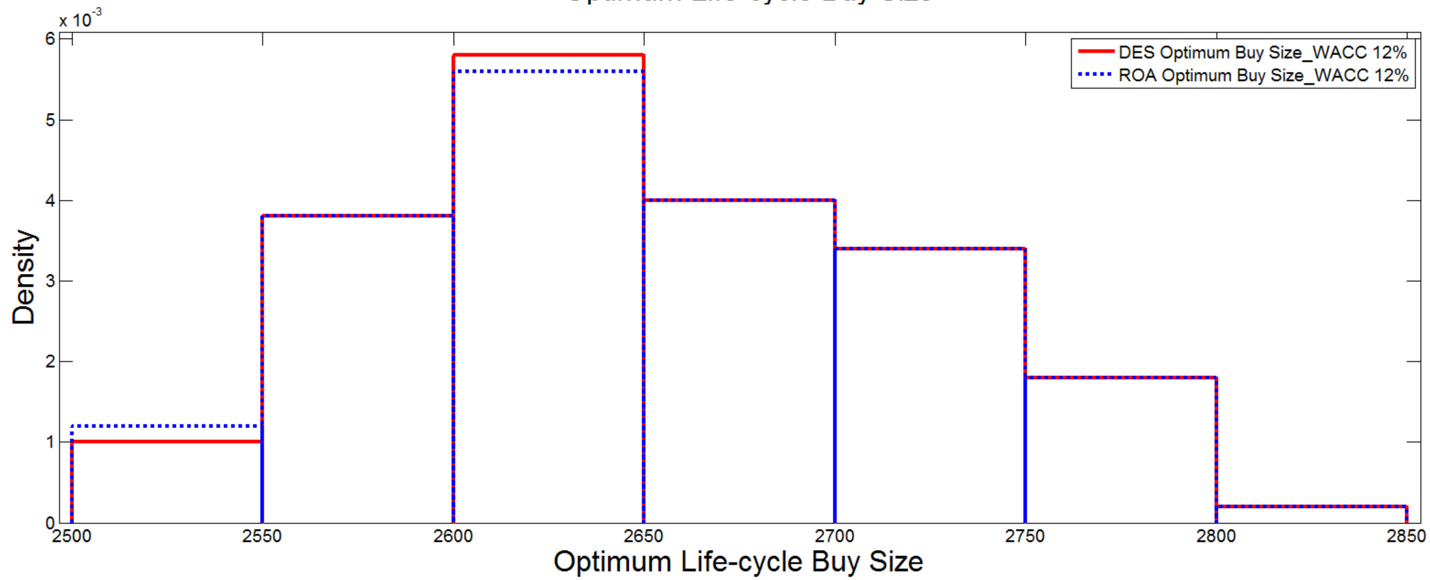
- Generated by varying the initial buy size and costing each demand path
- The minimum of this curve gives the optimum buy size (3047 parts)
- Note that, the optimum buy size is <u>not</u> the mean lifetime demand due to the fact that the penalties for over-buy and under-buy are not the same; the holding cost is not zero, and the demand is uncertain.

Comparison of DES and ROA

The optimum life-cycle buy size distribution for the example case from DES and ROA for WACC of 3%.



The optimum life-cycle buy size distribution for the example case from DES and ROA for WACC of 12%.



~1 part difference is due to real option analysis' inability to distinguish parts demanded at the same date

Conclusions

- Real options have been used in obsolescence management to assess the value of waiting to invest in new technology, but have not been previously used to assess lifetime or bridge buys.
- The optimum part quantity at which to exercise the "stopping the buy early" option and to perform a lifetime buy is determined.
- The optimum buy size from this method has been shown to be consistent with that from stochastic discrete-event simulation (DES) – due to a lack of flexibility in the management of the individual demand paths
- Different options are possible, e.g.,
  - The option to wait to make a lifetime buy – generally not an available option to DMSMS management
  - The option to buy more parts later (from a third party) – this is a viable option, but just shifts the problem of how many parts to buy at the lifetime buy to the third party
- Future work will include:
  - Examining the impact of a variable end-of-support (EOS) date
  - A fundamental problem that needs to be addressed is how to set the discount factor (WACC) for the analysis: risk-free, risk-neutral, risk-premium
  - Volume discount on number of parts → non-zero strike price

References

- Bradley, J. R., & Guerroro, H. H. (2009). Lifetime Buy Decisions with Multiple Obsolete Parts, *Production and Operations Management*, 18(1), 114-126.
- Cattani, K. D., & Souza, G. C. (2003). Good Buy? Delaying End-of-Life Purchases, *European J. of Operational Research*, 146, 216-228.
- Feng, D., Singh, P., & Sandborn, P. (2007). Optimizing lifetime buys to minimize lifecycle cost. *Proceedings of the 2007 Aging Aircraft Conference.* Palm Springs, CA, USA.
- Josias, C. L. (2009). Hedging Future Uncertainty: A Framework for Obsolescence Prediction, Proactive Mitigation and Management (Doctoral Dissertation). University of Massachusetts, Amherst, USA.
- Leifkera, N. W., Jones, P. C., & Lowe, T. L. (2014). Determining Optimal Order Amount for End-of-Life Parts Acquisition with Possibility of Contract Extension. The Engineering Economist. 59(4), 259-281.
- Porter, G. Z. (1998). An Economic Method for Evaluating Electronic Component Obsolescence Solutions, *Boeing Company White Paper*.
- Sandborn, P. (2013). *Cost Analysis of Electronic Systems*, World Scientific Publishing Co, Chapter 16.
- Singh, P., & Sandborn, P. (2006). Obsolescence Driven Design Refresh Planning for Sustainment-Dominated Systems, *The Engineering Economist*, 51(2), 115-139.
- Teunter, R. H., & Fortuin, L. (1999). End-of-life service. *International Journal of Production Economics*. 59, 487-497.
- Teunter, R. H., & Haneveld, W. K. (1998). The “final order” problem. *European Journal of Operational Research*, 107(1), 35-44.